The Importance of Antenna Matching

Proper matching of the feedline to the antenna can make the difference in antenna performance. McCoy shows you what to look for.

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One of the real problems for neophytes in amateur radio is understanding antennas, particularly when the subjects of bandwidth, standing wave ratios, and feedlines are brought up. If the newcomer turns to antenna text books written for engineers and enginering students, he may very well throw up his hands in disgust and take up stamp collecting.

The subject of feeding an antenna can be a very complex one, involving extensive mathematic calculations. On the other hand, it is possible to make some valid assumptions in which case, only simple math is required. We are going to use the simple approach to explain the problems — and the cures. By the way, if you are studying for an antenna theory exam, you will probably want to stick with your textbooks. I'll be discussing the real world and not some ivory-tower theory about how things "ought" to be.

Modern Transceivers

In recent years, transceivers have changed in design so that in order to put out their rated power, they must be operated into a 50-ohm load. If the load varies much from the 50-ohm figure, the transmitter amplifier will actually shut down. Usually, the mismatch must be no greater than 2 to 1. The problem is compounded because while it is easy to design a system that will present a 50-ohm load on a single frequency, or a narrow band of frequencies, it can become difficult to have an antenna that will present this 50-ohm load on *all desired frequencies*. That is our problem.

The Antenna as a Load.

The feed point of an antenna and that feed-point impedance or load depends on many factors. The simplest antenna, and most efficient, is an ordinary half wavelength dipole. Usually, when antenna people discuss antenna patterns or theoretical impedances, they usually refer to the pattern or impedance obtained in free space. Free space is chosen because there are no influencing factors.

In free space, for example, the impedance of a half wavelength dipole is about 70 ohms. This same antenna above a perfect ground at a height of one half wavelength, will also be about 70 ohms. However, in the real world, amateurs hang antennas near other objects, trees, towers, buildings, or whatever, and these nearby objects have a definite influence on the antenna, changing the impedance to some other value.

It should also be added at this point, that the impedance at resonance of an antenna consists of only two properties, ohmic resistance and radiation resistance. Recall that the definition of resonance is that point where capacitive and inductive reactance cancel each other out. Normally, the ohmic resistance is only a few ohms, or even a fraction of an ohm. This is the actual resistance of the wire or tubing used in the antenna. The ohmic reistance of an antenna will dissipate power as heat — and serve no useful purpose. The rest of the power is fed to the radiation — or useful — resistance. With one ohm or less ohmic resistance and the rest radiation resistance in our 70-ohm antenna, one can quickly see that a dipole is an extremely efficient antenna. Most of the power is fed to the useful part of the impedance.

Note we said that this happens at resonance. At any other frequency we'll encounter reactance in the feed point. This is because the capacitive and inductive reactances are no longer equal and therefore don't completely cancel each other out. Unless we compensate for this reactance, it becomes more difficult to feed power to the antenna as the operating frequency moves away from resonance. Reactance is expressed in ohms also, but it is not a real resistance. It will not consume power — rather, it stops the flow of power into a circuit.

Another important point here is that if we shorten an antenna physically, the radiation resistance will drop in relation to the size of the antenna. As an example, suppose that we use an 80-meter whip antenna on a car and that the whip is eight feet long. The full size electrical 80-meter vertical whip would be about 65-feet long. Its radiation resistance would be on the order of 35 ohms. On the other hand, our 8 foot whip plus the necessary loading coil or circuit would be at least a sizeable fraction of an ohm — causing our ohmic resistance to be a very significant factor. Only a fraction of the power would be radiated versus the full size antenna. Therefore, the whips efficiency would be much lower than the full-size dipole's.

Whatever type of antenna we decide to use, it is always better to have a matched system — not necessarily a "matched" antenna, but a matched system. Such a system will always provide a better bandwidth than one that is unmatched.

Bandwidth

Bandwidth of an antenna is usually given in terms of how far one can change frequency and still keep the mismatch below 2 to 1 (a 2 to 1 SWR). Of course, the ideal situation would be to cover an entire amateur band with a bandwidth of less than 2 to 1, plus using a coax feed line, with as low a loss as possible. Staying just with half wavelength dipoles, this is not possible on the 80/75 meter band, but can be approached on 40 (usually 3 to 1 bandwidth for the whole band). It can be done on 20 and 15, but not on 10. On all the newer bands (12, 17 and 30 meters), it is very possible simply because the bands are not that wide.

Of course the big question is that if one uses a simple wire dipole, say on 80 meters, is it worthwhile attempting to match the 50-ohm feed line to the antenna to an exact match? Bear in mind that the feed line *must* be matched at the antenna. No doubt that it would help broaden out the SWR, but the 80 meter band is so wide it still wouldn't give 2 to 1 bandwidth for the entire band.

In plain language, it turns out that it really isn't worth attempting to match wire dipoles. One cuts and trims the antenna lengths to provide the lowest possible SWR for the desired operating range. However, don't despair; there is an answer to the problem that doesn't require matching at the antenna. Before going into that, let's us discuss where matching *is* required on dipole antennas.

Beams

Sometime in every amateur's life, he or she will use some type of beam antenna, be it on the low bands or at VHF. The feedpoint impedance of almost any single band Yagi is usually well below 50 ohms. As an example, a three-element Yagi, with spacing of elements of one/tenth wavelength or slightly more, will provide a feed impedance on the order of 10 ohms. This would mean a mismatch of 5 to 1 for 50-ohm coax, certainly an impossible load for our modern transmitter. There is no doubt we have to do something here to obtain a match in order to improve the bandwidth.

The most common method of matching single band beams is via what is known as a gamma match. Fig. 1 shows this type of device which consists of a capacitor and length of tubing or wire that is attached to the driven element of the beam. Tubing length and capacitor are chosen to provide a step up in impedance from the beam impedance to the 50 ohms of the feedline.

This matching provides us with a greater bandwidth for any given beam antenna. Assuming a 20-meter beam made for the center of the band, say 14,175 kHz, and matched to a perfect 50 ohms, the bandwidth for the entire band should be well below 2 to 1.

All of our bands where we would use a beam, 40 meters and up, would give a good bandwidth with a matched condition — certainly useable enough for modern transceivers. The exception is 10 meters where we have 1700 kHz available. However, even here we can come up with pretty good bandwidth.

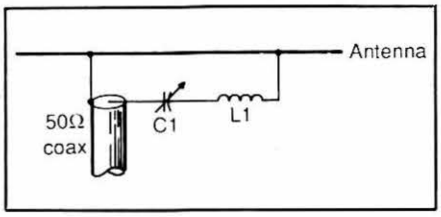

Fig. 1 — Gamma matching. The gamma match consists of C1 and L1. L1 is usually a piece of tubing spaced a couple of inches from the driven element. The point of attachment of L1 to the antenna is found experimentally and is usually not critical. C1 is adjusted to a 1-to-1 match.

Bear in mind that this is for monoband beams. Multiband beams with single feed are not as simple to match. Impedances are extremely complex and sacrifices must be made in the performance of such antennas in order to obtain usable bandwidths. Such antennas are mostly commercially made. The manufacturer finds it impossible to design one antenna to meet all conditions. Remember, it was stated earlier that height above ground, surrounding objects, and so on, all effect the bandwidth and impedance of an antenna. Each of us has a unique antenna location.

Transmatches or Antenna Couplers

The simple answer to always presenting a 50-ohm load to the transceiver is to use a transmatch. A transmatch is an adjustable RF transformer which takes unknown load on the antenna side of system and converts it to 50 ohms. Many, many conditions are met by using a transmatch. The most important condition is what we just mentioned—this method always provides a 50-ohm load to the transmitter. Additionally, assuming the transmatch is a selective circuit, and most are, the unit will provide additional selectivity to your receiver.

For another thing, the transmatch will provide some degree of harmonic attenuation — whether you need it or not. Most important, of course, is that the transmatch will always give you a load that the transmitter wants to see. It also increases bandwidth simply because you are always operating from a matched condition.

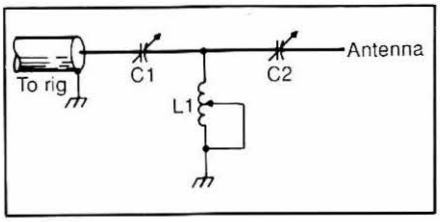

Fig. 2 — The common transmatch configuration. For multiband operation (80 through 10), C1 is usually 200 to 250 pF and C2 is 300 pF. L1 is an adjustable inductor (roller inductor) with a maximum value of 20 to 30 uH.

Fig. 2 is a common transmatch circuit and one that will match any load. When I use the word "any" I mean just that — any load. Some may be more critical than others, but it will match anything. However, that in itself may not always be to the user's advantage simply because there are some conditions with certain mismatches that could cause problems. We will treat those soon, but first let's discuss feedlines a bit.

Transmission lines

There are a few basics that should be set down when discussing transmission lines. Regardless of the type of line, coax or open-wire, the inherent losses in a line depend basically on three factors: the actual conductor losses or resistance, the losses introduced by the dielectric material used to separate or support the conductors, and last, the frequency used. This last is very important because as we go higher in frequency, the losses increase, and sometimes dramatically.

Dielectric losses are, of course, most pronounced in coaxial feedlines. In this case, the inner conductor is separated from the outer conductor by a sheath of dielectric material and the outer conductor has an external sheath for weather and insulation protection. It is this inner sheath that separates the two conductors that gives coax its high loss factor.

Open-wire line and the popular 450 ohm type Twin-Lead don't have anywhere near the losses of coax when it comes to dielectric losses. Most important in the case of open-wire line is that for all practical purposes, it is lossless from 160 though the 10-meter band. This means that we can tolerate extremely high standing wave ratios using open wire line. Such high SWRs may cause other problems, though. However, for the moment, let's get back to coax.

Another factor we must note is that as the mismatch at the antenna becomes greater so does the SWR on the line. And, as the SWR goes higher, so do the losses in the line. In radio, these losses are expressed in decibels. For many amateurs, it is much easier to understand if the decibels are actually converted to watts. That is what I am going to do here.

So keep in mind the following facts. The losses in coax can be attributed to:

- The dielectric material used to separate conductors.

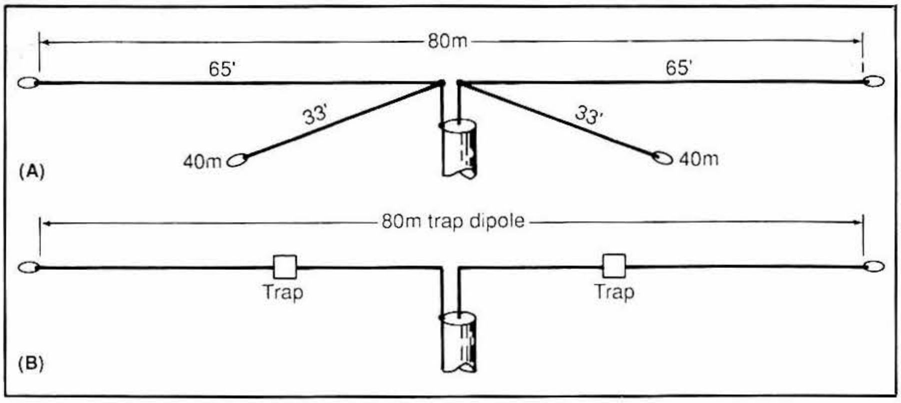

Fig. 3 — At "A," two dipoles attached to a common feedline. Parallel dipoles will usually provide a match, at the worst, of less than 5 to 1 on all bands. It can be highly reactive, but with the transmatch circuit shown in Fig. 2, this system can be used with good success with 50-ohm coax, providing a 1-to-1 match for the transceiver.

- •The size or inherent ohmic resistance in the wire.
- •The frequency in use. The higher the frequency, the greater the loss.
- •The losses because of standing wave ratio.

How Bad Can It Get?

Probably the best illustration of losses is what could be called a "worst case" situation. Let's suppose we have a half-wavelength dipole on 80 meters, 130 feet or so overall, either horizontal or inverted V, and fed with 100 feet of 50-ohm coax. Let's make the coax RG-58, which is a lossy cable. Also, let's assume we are using a transmatch that can be adjusted to compensate for *any* mismatch, regardless of the magnitude of the SWR.

This 80 meter half-wave antenna, depending on its height and configuration, will have an impedance (or feed-point load) of anywhere from about 30 to 100 ohms. It would provide a reasonable match for the 50-ohm line. In other words, the SWR should be not much greater than 2 to 1. Now let's assume we use this same antenna on 40 meters. Instead of a center-fed half wavelength it is now a center-fed *full* wavelength and the feed point impedance goes extremely high — somewhere near 4000 ohms. This means a standing wave ratio of about 80 to 1! So we have on 80 meters, an SWR of less than 2 to 1, and when using 40 meters, 80 to 1. The transmatch will match in both cases.

RG-58 coaxial cable has a very insignificant loss factor on 80 and 40 meters, only 0.80 decibels per 100 feet of coax at 80 and approximately 1.4 at 40 meters. With 100 watts going into the line from the transmitter, and assuming an SWR of 2 to 1, the 0.80 dB loss is almost impossible to measure with ordinary amateur test equipment. However, when we go to 40 meters and the 80-to-1 mismatch, the additional losses because of SWR rise to an astronomical figure.

With our 100-watt power and 100 feet of line, only a very small fraction of the power will reach the antenna, something much less than 10 watts! Also, we must factor in one more problem when we use coax that is badly mismatched. It is dangerous to run high power when coax has a bad SWR on the line.

The line can heat or actually puncture because of high rf voltages and break down. Without becoming too technical, the higher the SWR, the higher the RF voltage on the line. That is also true of the current and, hence, the heating.

The example just given is a worst-case condition but there is an answer to such a problem — in fact, several answers.

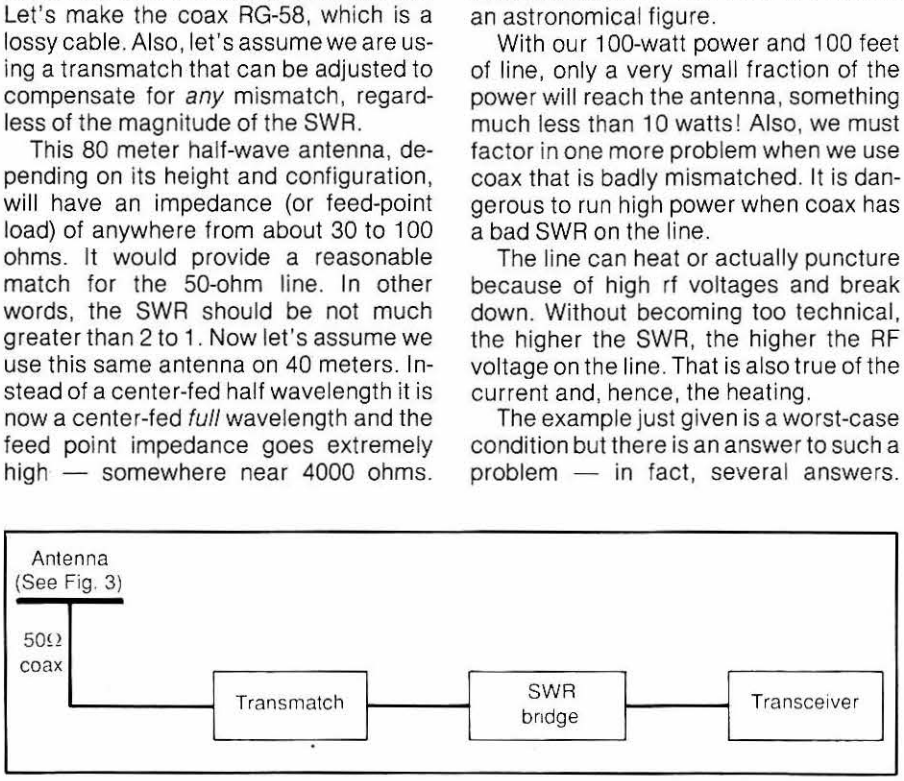

Fig. 4 — This would be a typical setup using a transmatch to provide a 1-to-1 load on all frequencies.

Open wire feeders are, for all practical purposes, lossless as a transmission line. For this reason, one can tolerate extremely high standing wave ratios without losses. The 80-to-1 mismatch when using a 2- or 4-inch open-wire line would not be worth thinking about. Keep in mind that if a transmission line is lossless, the power *has* to go to the antenna and be radiated — without any loss.

However, regardless of what we say here, many amateurs prefer using coax — and there is nothing wrong with that assuming we set up certain guide lines. For example, RG-8 types of coax can easily support mismatches of up to 10 to 1 at full power levels without any serious problems in the line. Using this coax, let's take any of the many types of multiband dipoles, either with traps or parallel dipoles as shown in Fig. 3, and see what we are faced with.

Suppose we make one of the 80- through 10-meter dipoles shown in the handbooks — one using traps. On 80 meters, going completely across the band, we can expect standing wave ratios of up to 7 to 1 or 8 to 1, depending on where we make the antenna resonant. Certainly we could not use that antenna with anything over 2 or 3 to 1 with our modern transceiver, since it would likely shut down. Suppose though, we add the transmatch circuit shown at Fig. 1 — or one similar. We can connect it in the circuit as shown in Fig. 4, take the unknown load of the antenna system and convert it to 50 ohms. As I said, we can live with an SWR of 10 to 1 on coax. In fact, in watts or S-meter readings, I sincerely doubt one could tell the difference between a perfectly matched dipole and this system.

What about the other bands with this multiband dipole? Simple. In nearly all cases, 40, 20, 15, etc., the mismatch is not going to be much more than 3 to 1 in the worst case, so there's little likelihood of problems. The parallel dipoles shown in Fig. 3 is a good simple system to tune using a transmatch. I have used a 40-meter dipole in parallel with an 80 meter on all bands. The mismatch is not too bad — worst case less than 10 to 1, on any of the bands so the tuned coax system works.

Many amateurs have asked if I use a transmatch with a multiband beam. The answer is simple: If I have to, I do. I would prefer to have a matched condition rather than one of, say, 2 to 1 simply because of the transceiver design. This means that I am again presenting a matched condition at all times to my transceiver. This is something I really like doing since everything runs more efficiently and much cooler.

In conclusion, don't be afraid to use a Transmatch or tuner with coax—just make sure that you are operating the coax within its limits.